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Role of Antecedent Soil Moisture and Vegetation Stress in Lightning-Initiated Wildfires

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Abstract / Introduction

Lightning-caused wildfires are a small percentage of all wildfire events within the Conterminous U.S. (CONUS), but they account for over 56% of the acreage burned. The atmospheric conditions favoring wildfire and rapid growth are understood well: large dewpoint depressions, unstable planetary boundary layer, strong winds, etc. However, antecedent land surface conditions affecting dead and live fuel moisture is more difficult to quantify. This study examines over 20 years of antecedent land surface, vegetation stress, and wildfire characteristic data associated with nearly 77,000 lightning-initiated wildfires from the U.S. Forest Service Wildfire Database. We will invoke two in-house databases generated by the NASA Short-term Prediction Research and Transition (SPoRT) Center: an observations-driven, climatological run of the Noah land surface model within the NASA Land Information System (i.e., SPoRT-LIS) to depict soil moisture deficits / anomalies, and a satellite-constrained Evaporative Stress Index (ESI) product to denote areas of stressed vegetation. We will mine these datasets associated with lightning-caused (and null) events to determine important relationships, distributions, and delineators that correspond to elevated threat areas for lightning-initiated wildfires.

Dataset Descriptions

Wildfire and Lightning Databases

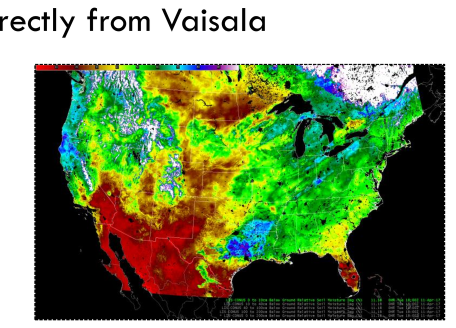
USDA Spatial wildfire occurrence data for the United States, 1992-2020

- Short, Karen C. 2022. Spatial wildfire occurrence data for the United States, 1992-2020 [FPA_FOD_20221014]. 6th Edition. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2013-0009.6

Vaisala National Lightning Detection Network (NLDN), 1995-2020

- NLDN data acquired by NASA/MSFC via contract, and can be requested directly from Vaisala

SPoRT-Land Information System (SPoRT-LIS), 1981-present



LIS is a land surface modeling and assimilation framework that SPoRT developed into an observations-driven, real-time system for soil moisture and land surface monitoring

- Runs Noah land surface model (lower-right) over full CONUS at ~3-km resolution
- Daily 1981-2015 soil moisture climatology; daily real-time soil moisture percentiles; hourly land surface outputs from March 2015 to present
- Experimental 14-day forecast soil moisture percentiles (driven by GFS)
- Incorporates real-time global VIIRS 4-km res Green Vegetation Fraction (GVF)

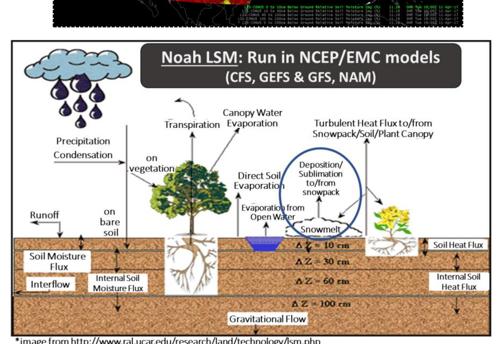
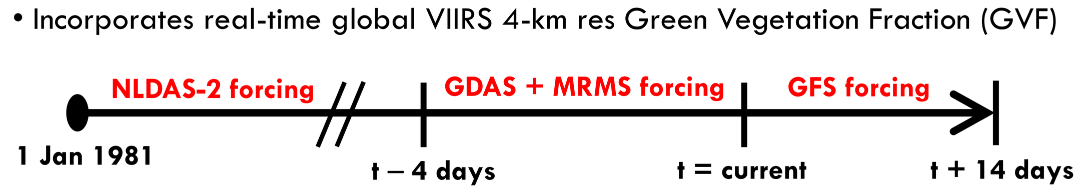


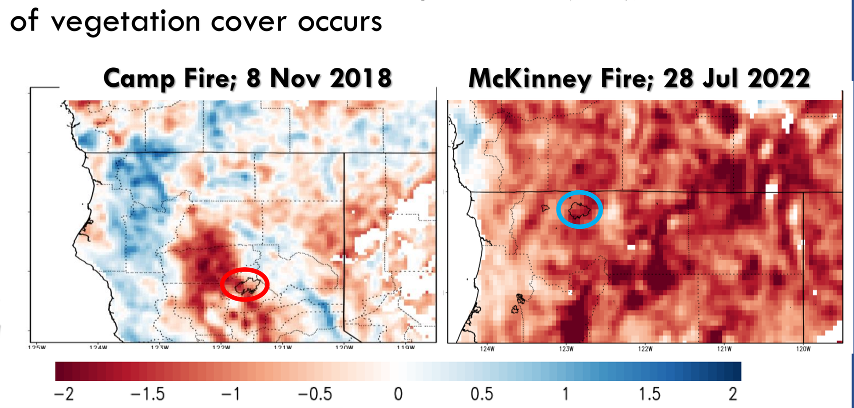
*image from http://www.ral.ucar.edu/research/land/technology/lsm.php



Land Surface: Evaporative Stress Index (ESI), 2001-present

ESI represents temporal anomaly in ratio of actual Evapotranspiration (ET) to potential ET for monitoring vegetation stress at 5-km resolution globally

- Anderson, M. C., C. Hain, B. Wardlow, A. Pimstein, J. R. Mecikalski, and W. P. Kustas, 2011: Evaluation of drought indices based on Thermal remote sensing of evapotranspiration over the continental United States. *J. Clim.*, **24**, 2025–2044, https://doi.org/10.1175/2010JCLI3812.1.
- Current surface moisture state is deduced directly from satellite Land Surface Temperatures (LST), and can therefore detect stress before deterioration of vegetation cover occurs
- ESI better represents "live fuel load" than remote sensing indices such as NDVI, which focuses on vegetation greenness
- Stressed vegetation may be susceptible to rapid fire growth before "brownness" is observed in NDVI



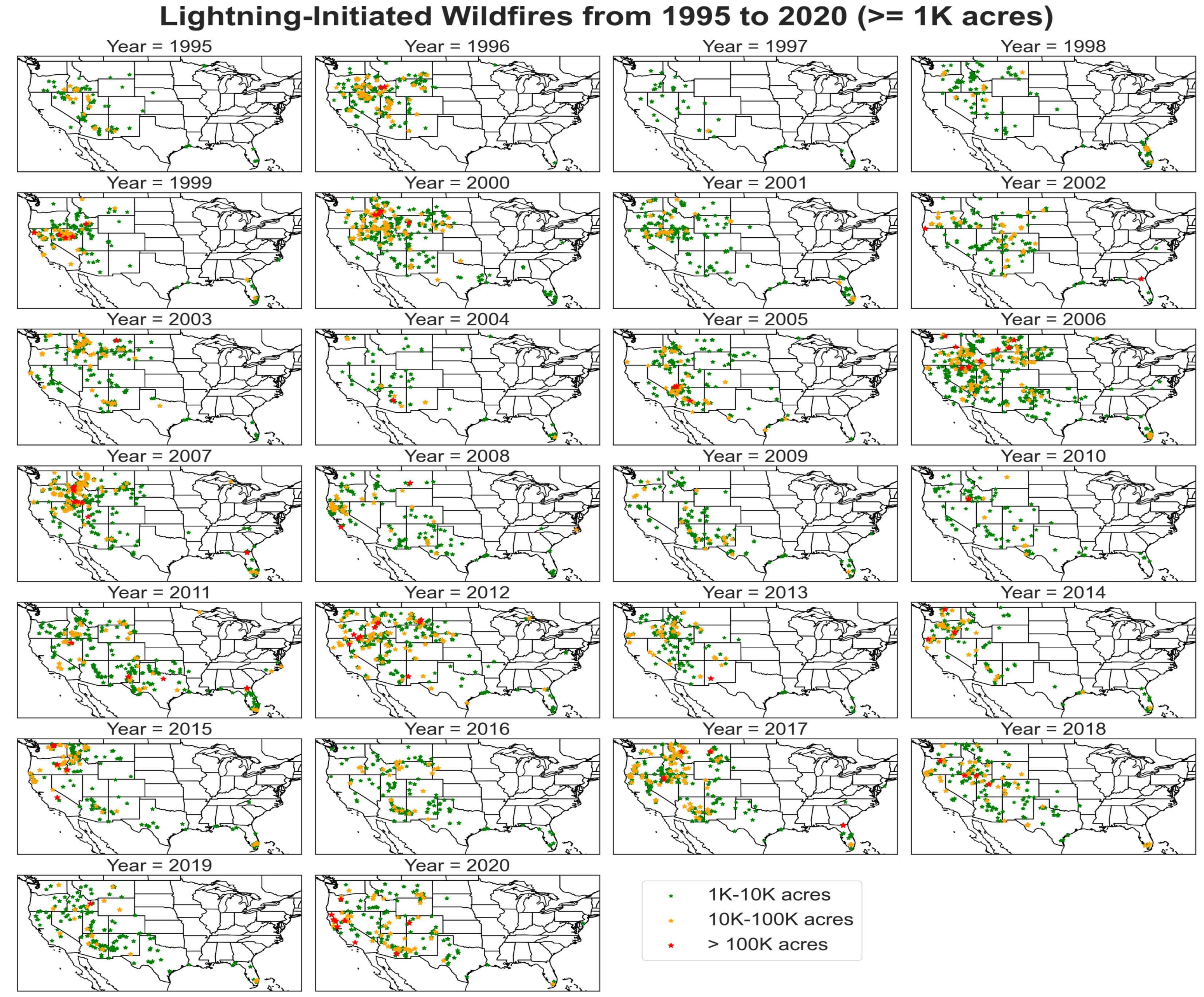
Four-week ESI change standardized anomalies for (left) Camp Fire on 8 November 2018; and (right) McKinney Fire on 28 July 2022.

Quantitative Precipitation Estimation (QPE)

Multi-Radar Multi-Sensor (MRMS) QPE Product, 2010 to present

- Zhang, J., and Coauthors, 2016: Multi-Radar Multi-Sensor (MRMS) quantitative precipitation estimation. *Bull. Amer. Meteor. Soc.*, **97**, 621-638, doi:10.1175/BAMS-D-14-00174.1.

Lightning-Initiated Wildfires from 1995 to 2020 (>= 1K acres)



Methodology

Wildfire and lightning pre-processing

- Identify all lightning-caused wildfires and include NLDN flashes within 10 km
- Focusing only on lightning-caused wildfires > 4 km^2 (~1000+ acres) in size
  - ✓Burn footprints comparable to input datasets (LIS [3 km], GVF [4 km], and ESI [5 km])
  - ✓Eliminates smaller fires reported by some states that may be structural fires
- Include flashes within 2 weeks of fire start to account for possible hold-over fires
- Group Lightning Initiated Wildfires into Geographic Area Coordination Centers
- Denote closest lightning strike to wildfire start location as the fire-starter
- All other lightning strikes are considered non-fire-starters.

Obtain SPoRT-LIS land surface variables at lightning locations

- Relative soil moisture (RSM; percent saturation between wilting and saturation) at each model layer and integrated layers (0-0.1, 0.1-0.4, 0.4-1.0, 1.0-2.0, 0-1.0, and 0-2.0 m)
- MODIS/International Geosphere-Biosphere Programme land-use classification
- VIIRS GVF from Sep 2012 – present; MODIS climatology GVF prior to Sep 2012

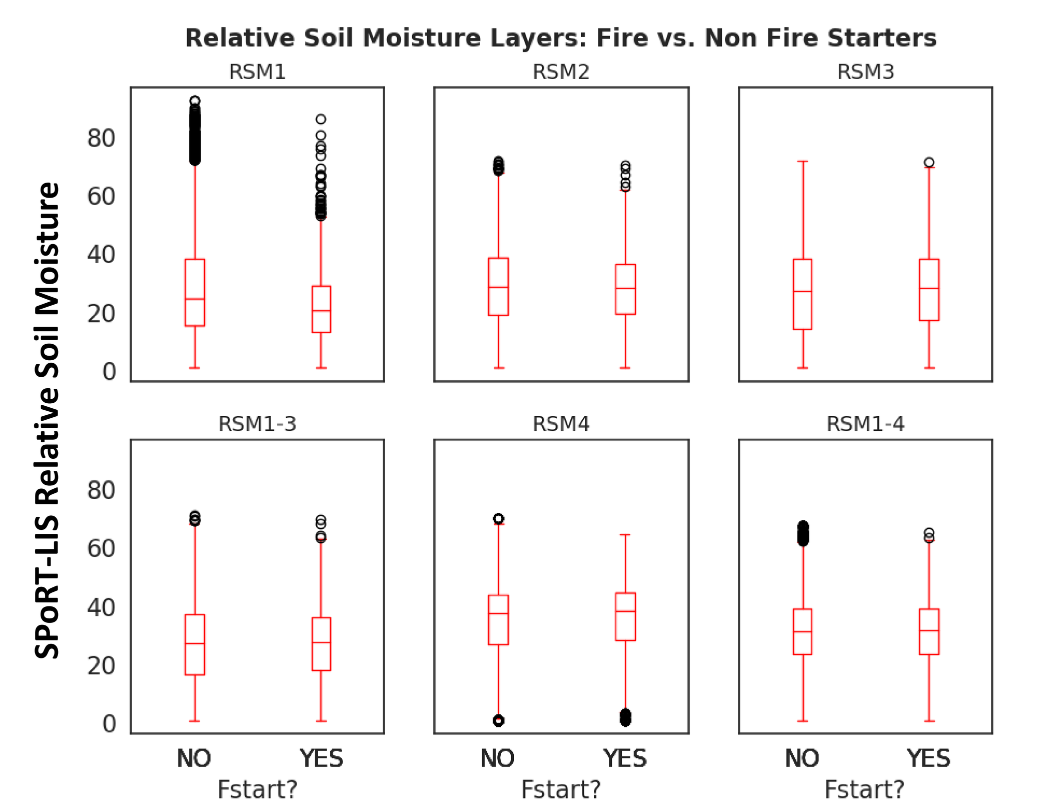
Extract MRMS QPE at lightning strike locations

- Obtain hourly QPE at t-1, t_0, and t+1 hours relative to the lightning flash times.

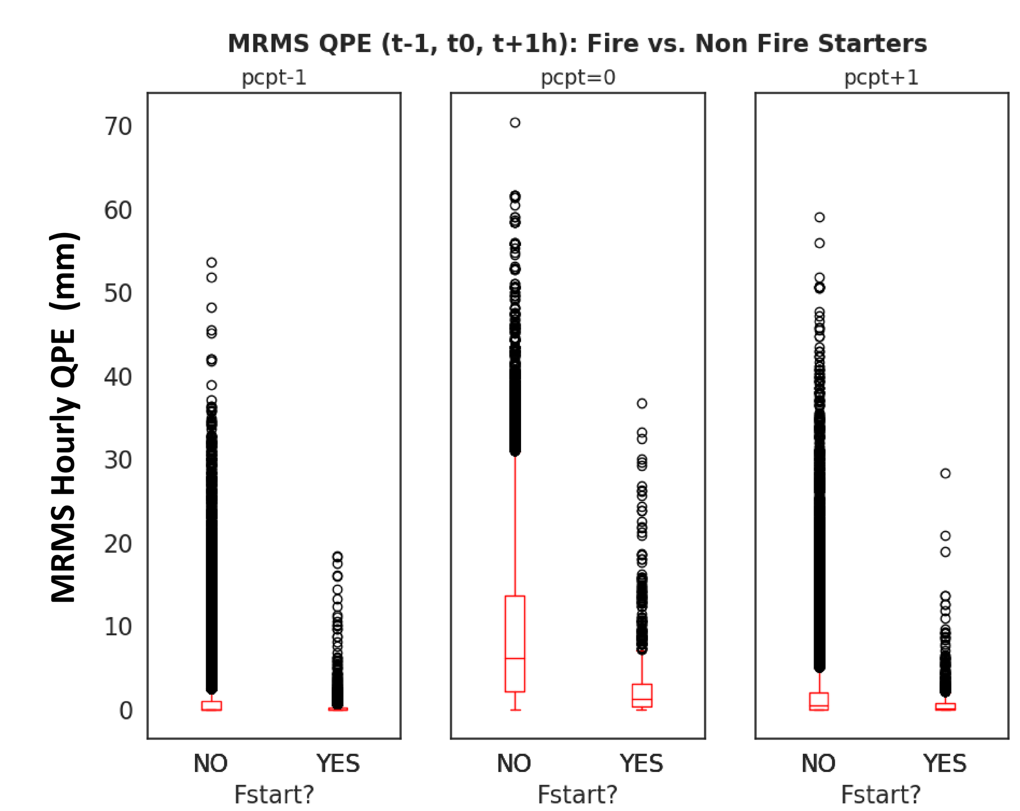
Obtain ESI standardized anomalies at lightning locations

Use nearest-neighboring grid points for all data extractions

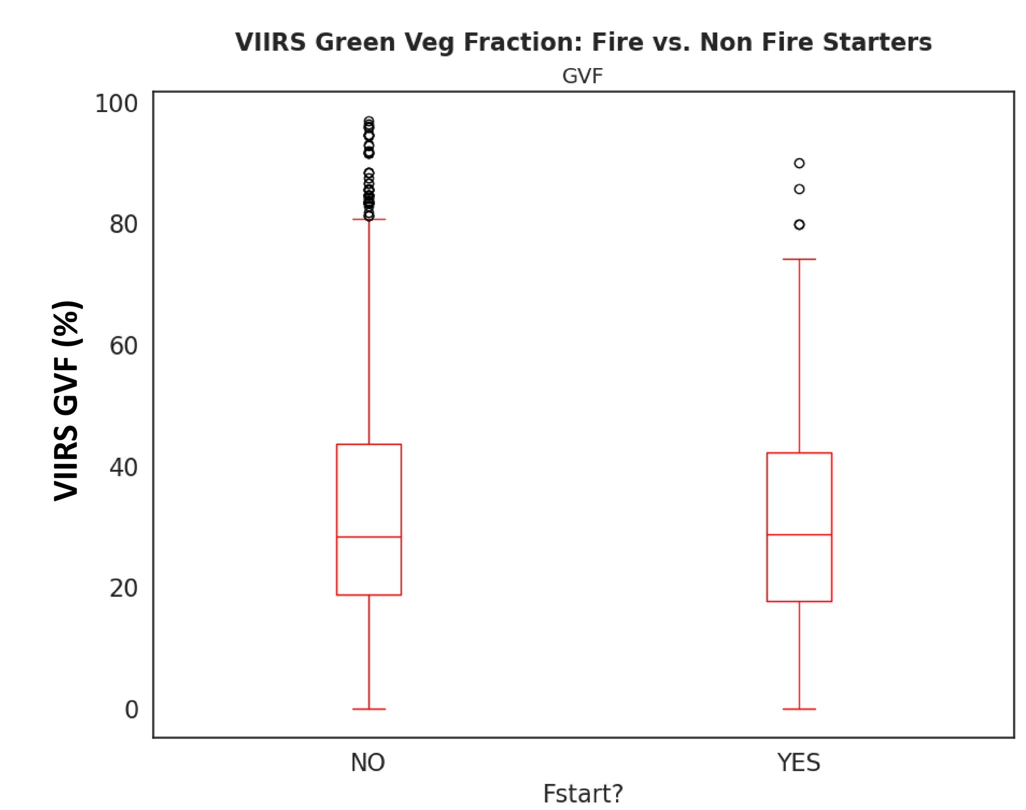
Preliminary Results (2015-2020) and Future Direction



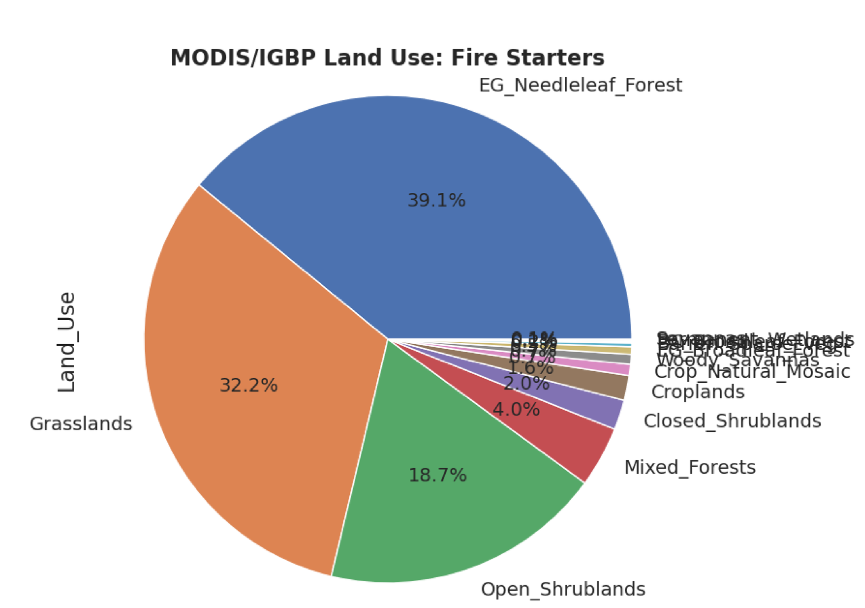
(above) Boxplots of SPoRT-LIS Relative Soil Moisture (RSM) at fire-starter vs. non-fire-starter lightning flashes for Noah land surface model layers 0-10cm depth (RSM1), 10-40cm (RSM2), 40-100cm (RSM3), 100-200cm (RSM4), 0-100cm (RSM1-3), and 0-200cm (RSM1-4).

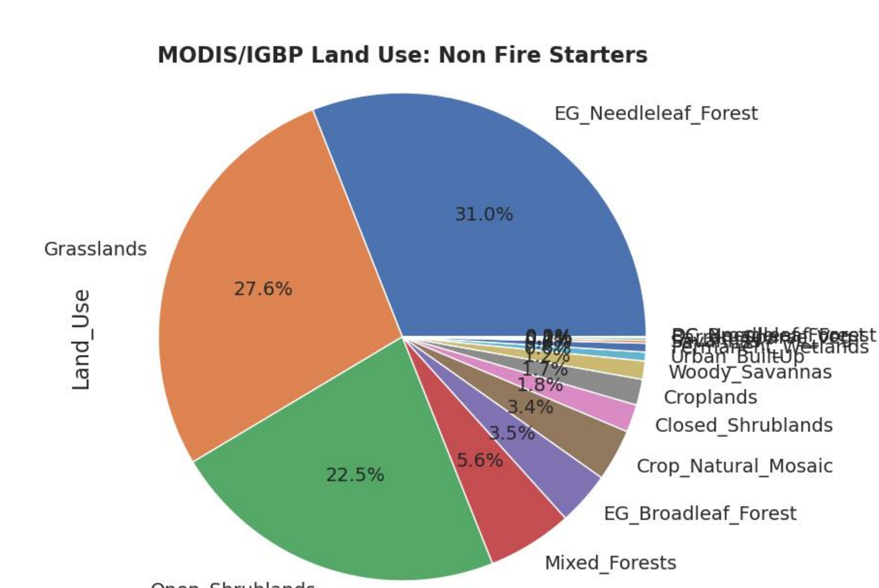


(above) Boxplots of Multi-Radar Multi-Sensor (MRMS) Quantitative Precipitation Estimation (QPE) at fire-starter vs. non-fire-starter lightning flashes.



(above) Boxplots of VIIRS Green Vegetation Fraction (GVF) at fire-starter vs. non-fire-starter lightning flashes.





High-level Initial Take-Aways:

- Results consistent with our prior research, indicating that only top-layer soil moisture has noticeably different distributions.
- Precipitation rates at lightning strike locations crucial distinction between fire starters and non-starter flashes.
- No substantial differences in GVF and land-use/land-cover class.

Future Direction:

- Process Evaporative Stress Index at lightning strike locations.
- Backfill to prior years, as data are available (MRMS only back to 2010).
- Dissect results by geographical region, land-use class, etc.
- Develop [probability / machine-learning] models for nowcasting wildfire initiation potential.